A MODEL FOR PRE-ARCING BEHAVIOUR SIMULATION OF H.V. FULL-RANGE FUSE-LINKS USING THE FINITE ELEMENT METHOD

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1 Introduction

In 1993 an agreement between Iberdrola SA and Ibérica de Aparellajes SL and the Grupo de Estudios en Distribución de Energía Eléctrica (GEDEE) of the Department of Electrical Engineering in the Polytechnic University of Valencia was signed in order to design and develop a Full Range Fuse for 20kV supply networks.

This paper shows the results of one of the stages of the project to obtain pre-arcing curves for different Full Range Fuse rated currents using finite element techniques (Section 2). The relationship between thermal and electrical processes and the different behaviour of the materials with temperature made us consider thermal and electrical effects coupled.

The design of the model used in the simulation experienced changes to match experimental results. Section 3.1 shows the different models developed to come to the present day model (3.2). Section 3.2.1 introduces the concept of *Equivalent Section*, a very useful concept which permits the use of simplifications in the model for Full Range operation fuses.

Section 4 describes the simulation procedure. Other possible model designs are shown in Section 5. The results obtained for the Full Range operation of the fuse and the validation of the model with experimental tests are shown in Section 6.

2 Techniques for the determination of pre-arcing curves

Of all the phases of fuse operation, this paper analyses pre-arcing. Time/current characteristics can be obtained with different simulation techniques: finite differences method [1] [2], electrical analogies for time/current characteristics in fuses using M-effect techniques[3], the simulation of heat transfer with parabolic differential equations [4], etc.

In this work, the finite element method has been chosen as a mathematical tool to solve differential equations systems with a good accurary [5]. This method allows to develop the simulation from a fuse geometry very similar to the real one so that once the properties of the materials are known (thermal conductivity, electrical resistivity, specific heat, etc) and their variations with temperature and loads (for example, flow intensity), the temperature at any point of the simulated fuse can be determined.

After defining the fuse geometry and properties of the materials (including their variation with temperature), the next step is to mesh the volumes generated, input applied loads and boundary conditions to solve the equations governing the physical phenomena.

Fuse geometry and properties of the materials, can be modelled at a minimum cost. Mesh design and equation resolution greatly affect calculation times; therefore a simplified model has been developed, which allows the calculations to be done in a shorter time.

3 Modelling

This section describes the different steps in model design and the introduction of the concept of *Equivalent Section.*

3.1 Model design

From the beginning of the project, the design of a model for fuses by the finite element technique changed to end with the model described here below (3.2). The first model used ignored the existence of a star core and supposes the fuse element (a equidistantly notched strip) to be along the fuse axis [1]. This was a three-dimensional model in which, even when some fuse elements are ignored and geometry simplified, calculation times are too long and there is no obvious improvement in accuracy.

Then, we tried the model of axial symmetry with two alternatives. The first alternative considered one central wire only; but this method did not allow to model a strip neither a star core nor several elements in parallel. The second alternative considered the fuse as a circular wound wire; this model allowed to model several elements in parallel, but it did not allow to reproduce strip notches. This second model was neglected as it did not allow to input current in a proper way.

A further model used a plain geometry, but the results obtained did not match very well with experimental tests as loads could not be input in a proper way. Finally we developed the model described below.

3.2 The model used

The fuse consists of a star core on which one or several silver strips are wound placed inside a porcelain barrel filled with granular quartz. The model allows the representation of the fuse geometry as well as of the different fuse elements and materials.

As the simultion of the complete fuse is impossible with our chances, it is necessary to simplify it to get reasonable calculation times. Size can be reduced by using symmetries, but because the helicoidal shape of the fuse does not permit it, other simplications were adopted: to model one helix step.

The helicoidal fuse shape on the star core allows two different approaches by the symmetry method: the first approach with the fuse element parallel to the star core and the second approach with the fuse element as circular wire turns. If the helix step of the fusible element is very big, it can be considered as parallel to the star core. In the case of High Full Range Fuses, because of the length of the elements, it will be closer to reality to consider them to be arranged as circular wire turns along the star core.

The simulated volume is defined between two parallel circular sections, perpendicular to the star core axis, on which the fuse element is mounted in circular shape, and separated half helix step, with the appropriate boundary conditions.

In order to include strip notches in this model, the arc considered must be long enough to generate a high number of nodes; but if an uniform-section strip is considered to be the fuse element (the *Equivalent Section* described in Section 3.2.1) wedge size can be reduced. The next step was to consider a paralelepiped with an uniform *Equivalent Section*, which simplifies the model and notably reduces calculation times with no increase in error values.

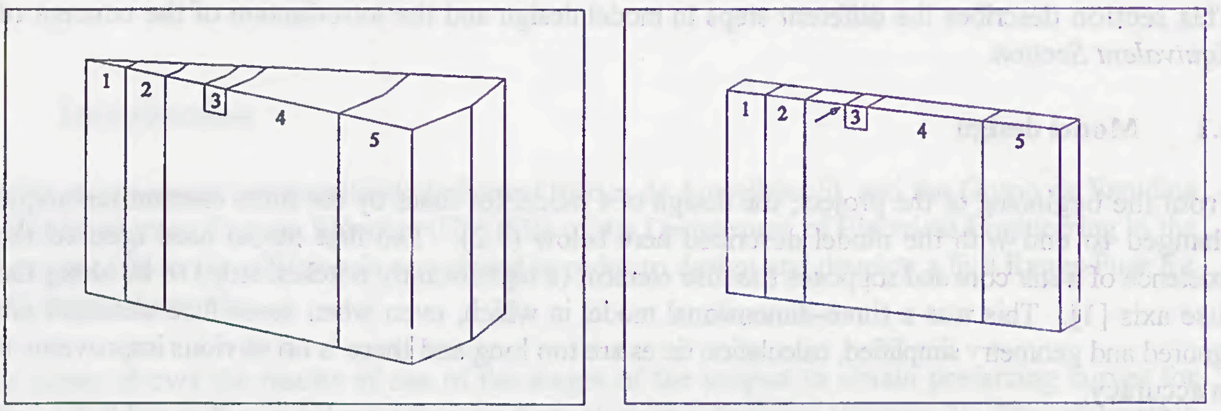

Fig. 1. Wedge and paralelepiped model.

The different parts of the model used, see Figure 1, are the granular quartz inside the star core (1), the star core (2), the fuse element (3), the quartz sand surrounding the fuse element (4) and the outer porcelain barrel (5). The fuse element is rectangular in section, and it was analysed as described below.

3.2.1 Equivalent section

Once the geometry of the fuse and the dimensions of each component element has been described, only to know the coil section for one step is left.

As this coil is of constant section, a relationship between it and a circular coil with all the strip notches existing in the real fuse was established. The definition of the *Equivalent Section* allowed us to know the variation law of the constant section to apply to each pre-arcing curve. *Equivalent Section* is the term given to that section which makes the circular coil in the model reach the melting point at the same time as the actual fuse strip under similar boundary conditions.

Contrarily to what might be thought, the *Equivalent Section* does not only depend on the notched strip geometry but also on the thermal and electrical properties of the material and on the melting current and time.

The *Equivalent Section* is determined with the method of finite elements by comparing the behaviour of notched strips and uniform section strips.

The results obtained are shown in Figure 2 for a semicircular equidistant notched silver strip (used in the validation tests). The results of the simulation and experimental data are shown in the following sections.

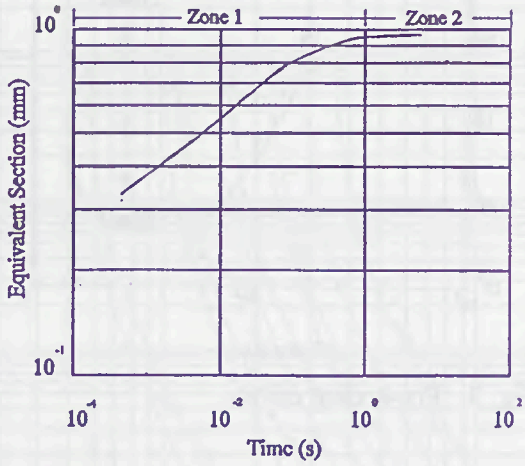

Fig. 2. Equivalent Section.

Zone 1, Figure 2, shows the relation between section and melting time in the area of quick melting, whereas in Zone 2 (long melting times) the *Equivalent Section* is almost constant.

4 Simulation procedure

The procedure of simulation has to be thought carefully because there are some parametres (*Equivalent Section*) and current, represented as a sinusoidal wave form or by its rms value, depending on the melting time.

Due to the variability of the *Equivalent Section*, the analysis should start with the long melting times, for which the *Equivalent Section* is constant and current is represented by its rms. For long melting times, fuse geometry is built from the *Equivalent Section* in Zone 2, Fig 2. The results corresponding to this simulated zone can be seen in Figure 3, Zone 2.

For intermediate melting times the *Equivalent Section* is variable (Zone 1 Fig 2) and current is represented by its rms.

Due to *Equivalent Section* variability it is possible for each pre-arcing section to require more than one simulation (Zone 1 Figure 3) .

For melting times shorter than one cycle (or a few cycles), current sinusoidal wavelength adequately discretized was used instead. The *Equivalent Section* in this zone shows a maximum variation with melting time.

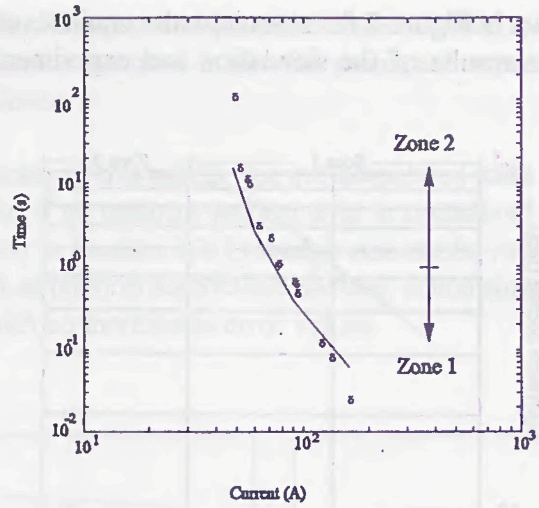

Fig. 3. Pre-arcing curve.

5 Applications, behaviour and validation of the model

Therefore, it will suffice to include some more coils turns with constant section in the simulated volume. Due to the symmetries considered in the model, the number of coils is half the number of elements in parallel, whenever it is an even figure, and one more half section turn, whenever it is an odd number.

Notched silver strips have a good performance for High Current; to ensure good full range fuse operation other techniques are used, which permit to widen the operating range. Among them are the use of intermediate heat chambers, a different material for the fuse element, M-effect, etc. Heat chamber can be easily simulated; it will suffice to use a material with different thermal conductivity round the fuse element. The use of materials with other thermal properties does not imply a change in the model, except for the varition law of the *Equivalent Section*.

6 Experimental tests

To validate pre-arcing curves obtained from mathematical calculations, experimental tests have been carried out to obtain time/current characteristics for different number of fuse elements and thicknesses of the strip.

Figure 4 (time/current characteristics) shows pre-arcing curves for two strip thicknesses and different number of strips in parallel, in comparison with experimental tests. Curves 1 to 6 are simulations with the same number of strips 0.12mm thick. Curves a,b,c,and d are simulations with 1, 2 3 and 4 strips 0.10 mm thick.

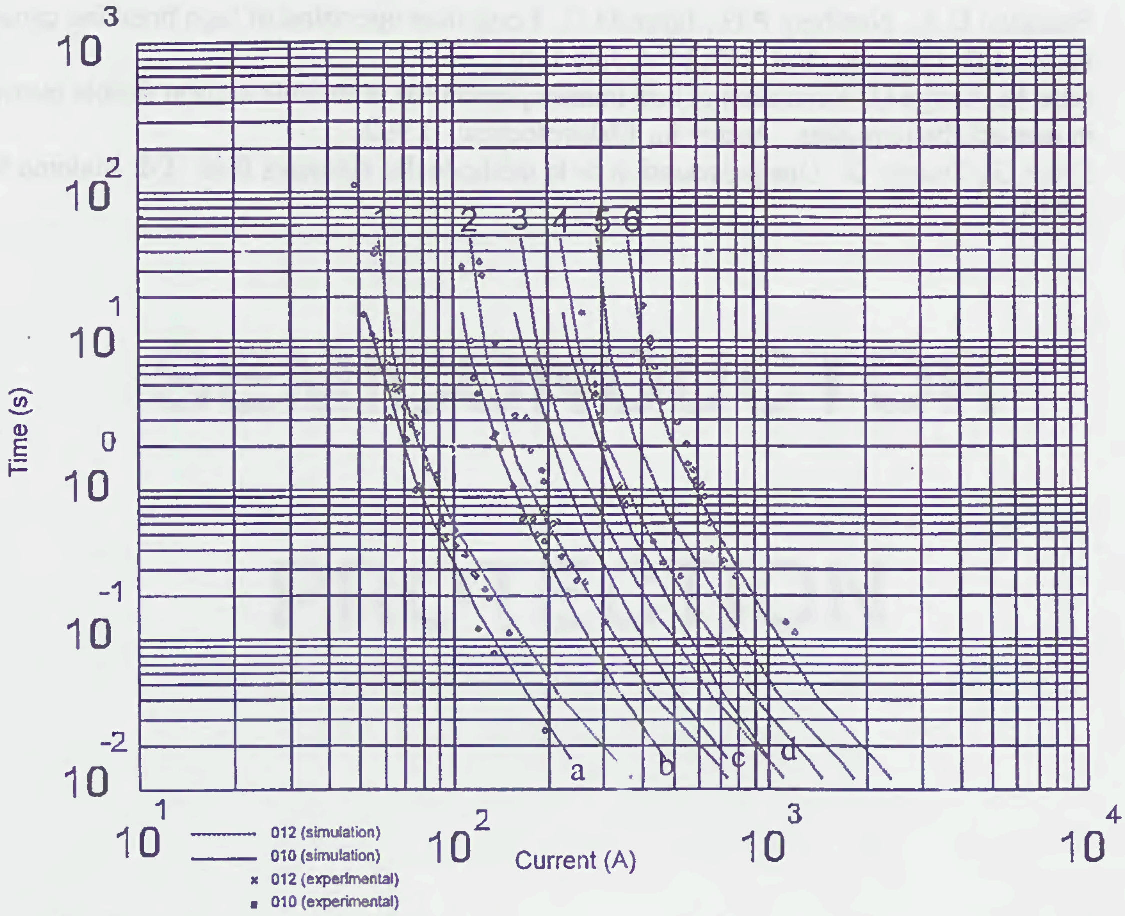

Fig. 4. Time/Current Characteristic

7 Conclusions

With the results obtained in the simulation, it has been proved with experimental data that the method used is accurate enough to determine pre-arcing curves not only in limiting fuses but also in the case of overload for Full Range Fuses.

This work tries to cover the complete pre-arcing curve as well as to simplify the model, like in simulations for overload currents. No simplified geometry models demand very long calculation times.

This article presents a new concept: the *Equivalent Section*, as a parametre affecting the geometry of the model, easy to use and which remarkably improves the accuracy in the results and calculation times.

8 References

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SEMICONDUCTOR

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